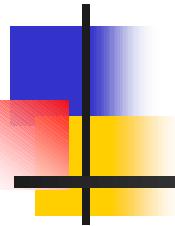


# Tri-Carbide Square Lattice Honeycomb (SLHC): An Innovative Reactor Design for All NTP Applications



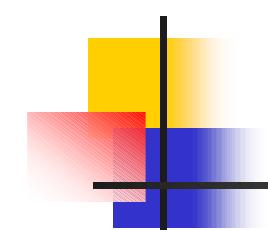
Samim Anghaie and Travis Knight

*Innovative Nuclear Space Power and Propulsion  
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Gainesville, FL 32611-6502  
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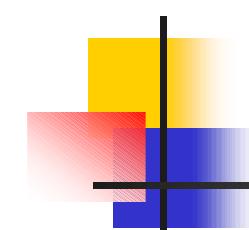
*<http://www.inspi.ufl.edu/>*



# Space Nuclear Power and Propulsion Research Program

- INSPI's focused area of research: Ultra-high Temperature Reactor Design and Energy Conversion
- SLHC Nuclear Rocket Engine, XNR2000, ESCORT, Gaseous and Liquid Core Space Power Reactors
- MHD Power Generation, Thermionics, Gas Turbine Cycle
- Ultra-high Temperature Materials and Nuclear Fuels

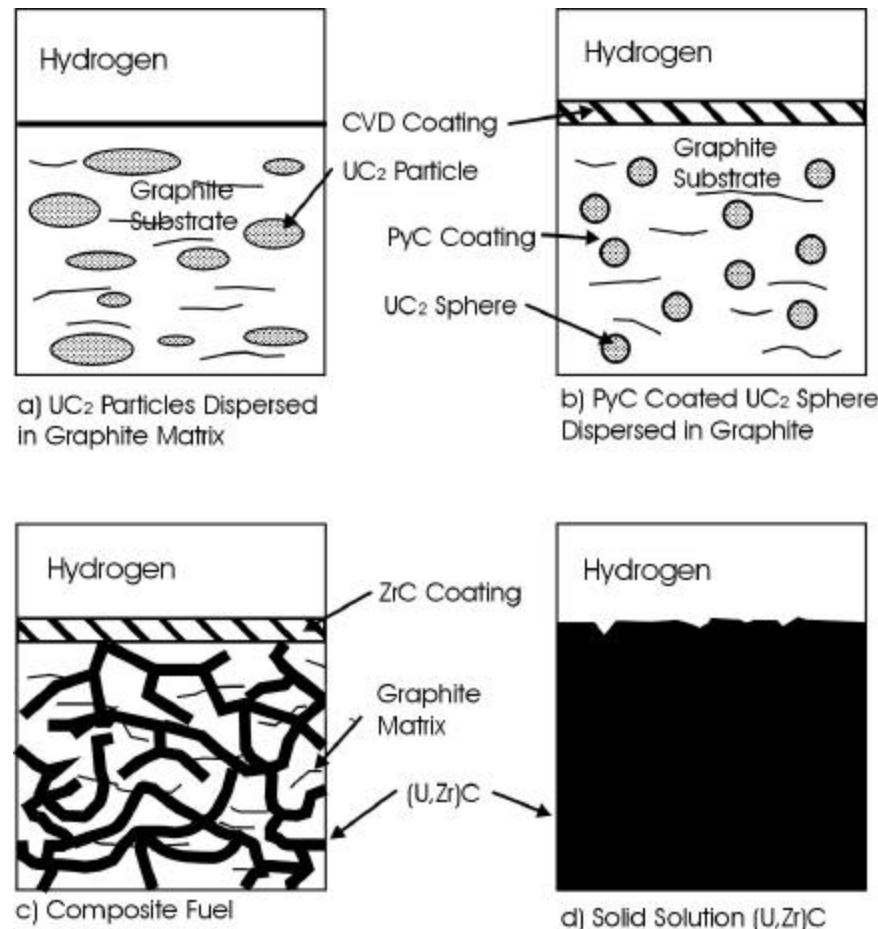


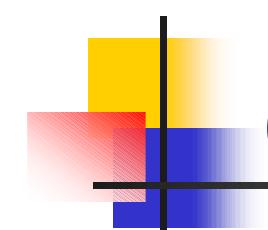


# Rover/NERVA Accomplishments

- Program duration from 1956 to 1971
  - 4500 MW/m<sup>3</sup> max. power density
  - 2600 K exhaust temperature
  - 250,000 lbf thrust
  - Isp=850 seconds
  - 90 min. burn time
  - T/W of 3 to 4
- 23 tests conducted at the Nevada Test Site; Nuclear Rocket Development Station, NRDS

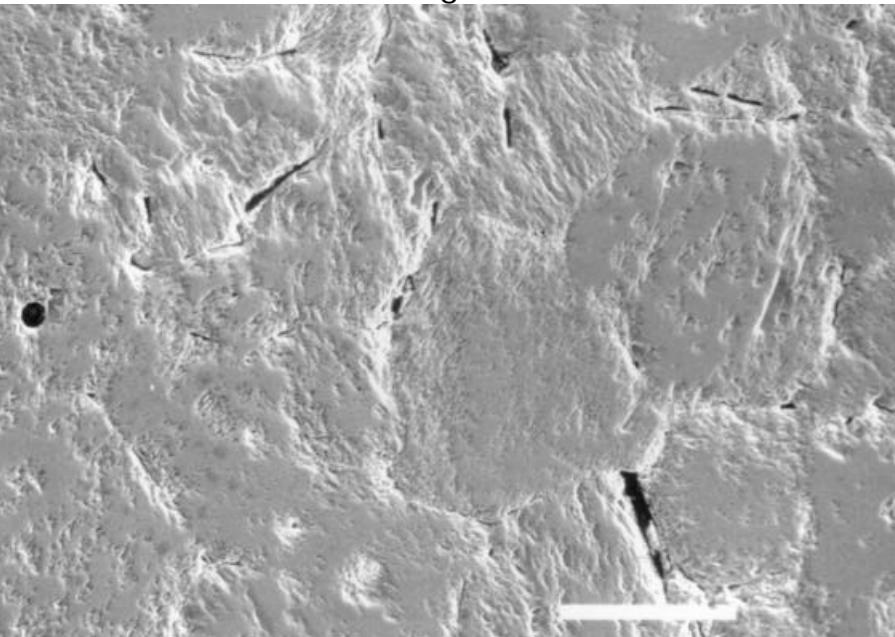
# Rover/NERVA Fuel Element Microstructure





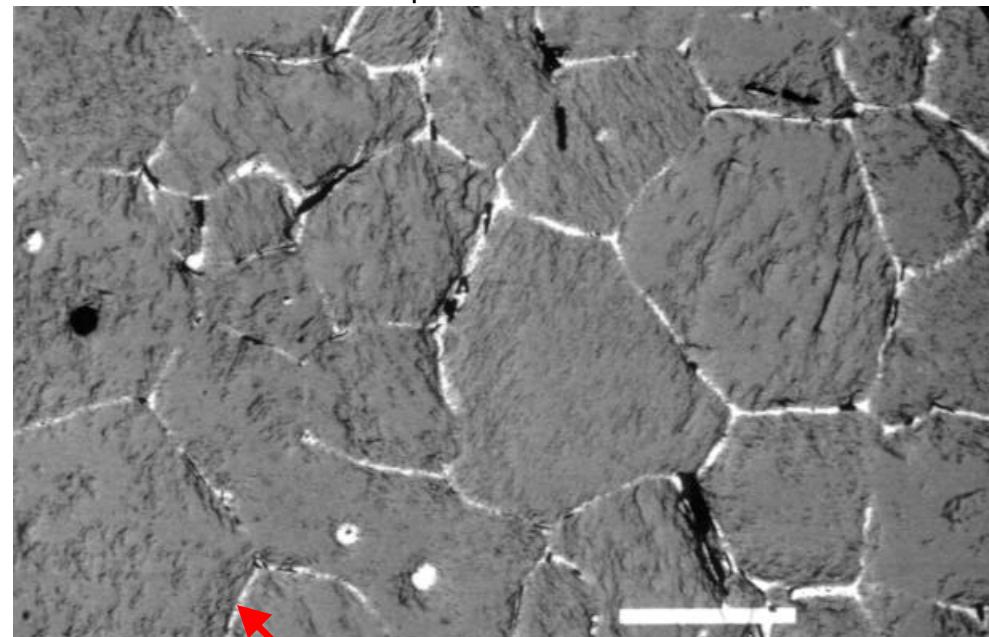
# $(U_{0.1}, Zr_{0.77}, Nb_{0.13})C_{0.95}$ Sintering, $T > 2800$ K

SEM Image: SEI



100 m

Composition Contrast: BSE



100 m

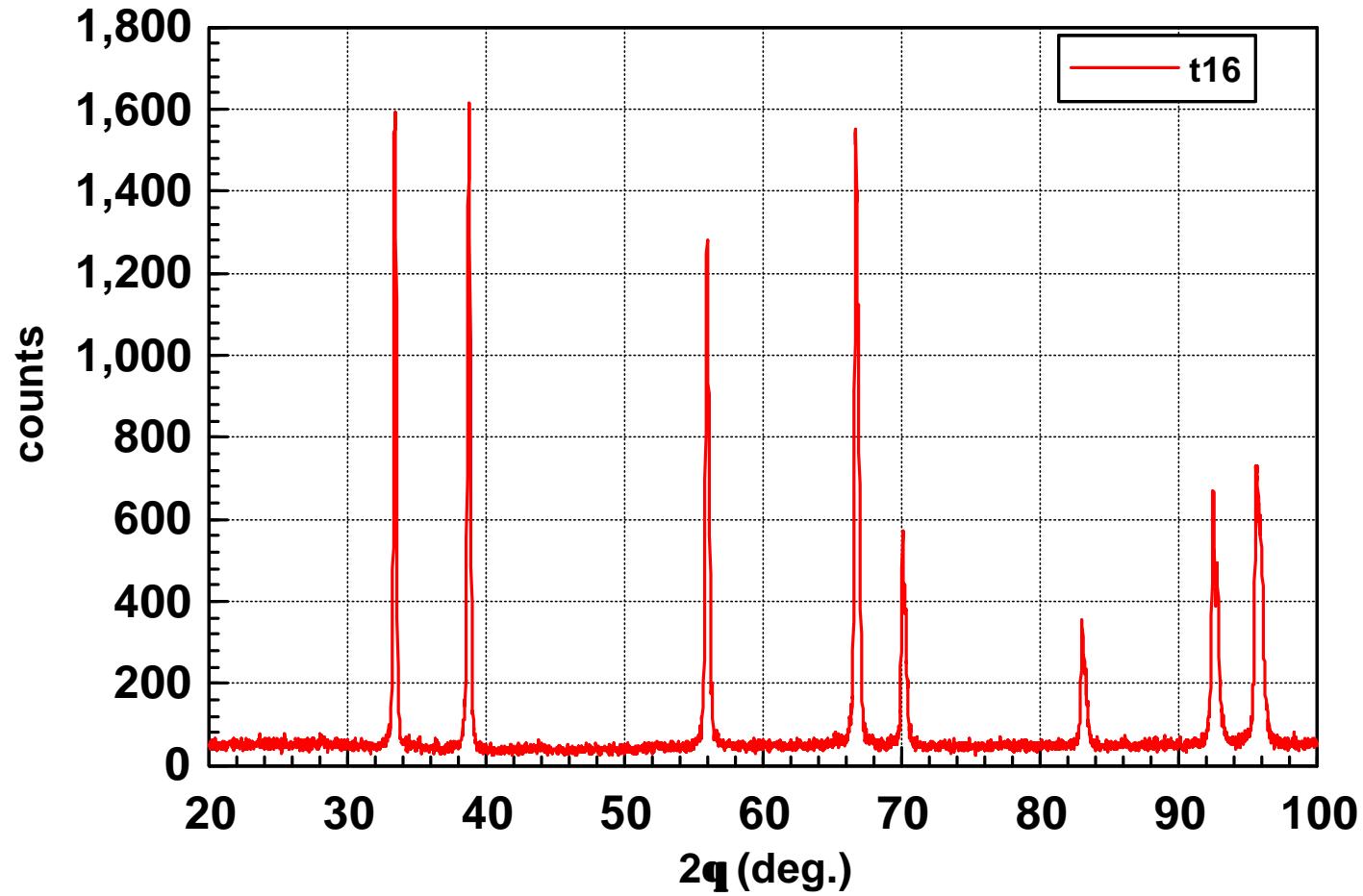
4 min.,  $>2800$ K  
128 min.,  $>2500$ K  
7.28 g/cc (96.5%TD)  
T18, Phase II

UC

# XRD ( $\text{U}_{0.1}$ , $\text{Zr}_{0.77}$ , $\text{Nb}_{0.13}$ ) $\text{C}_{0.95}$

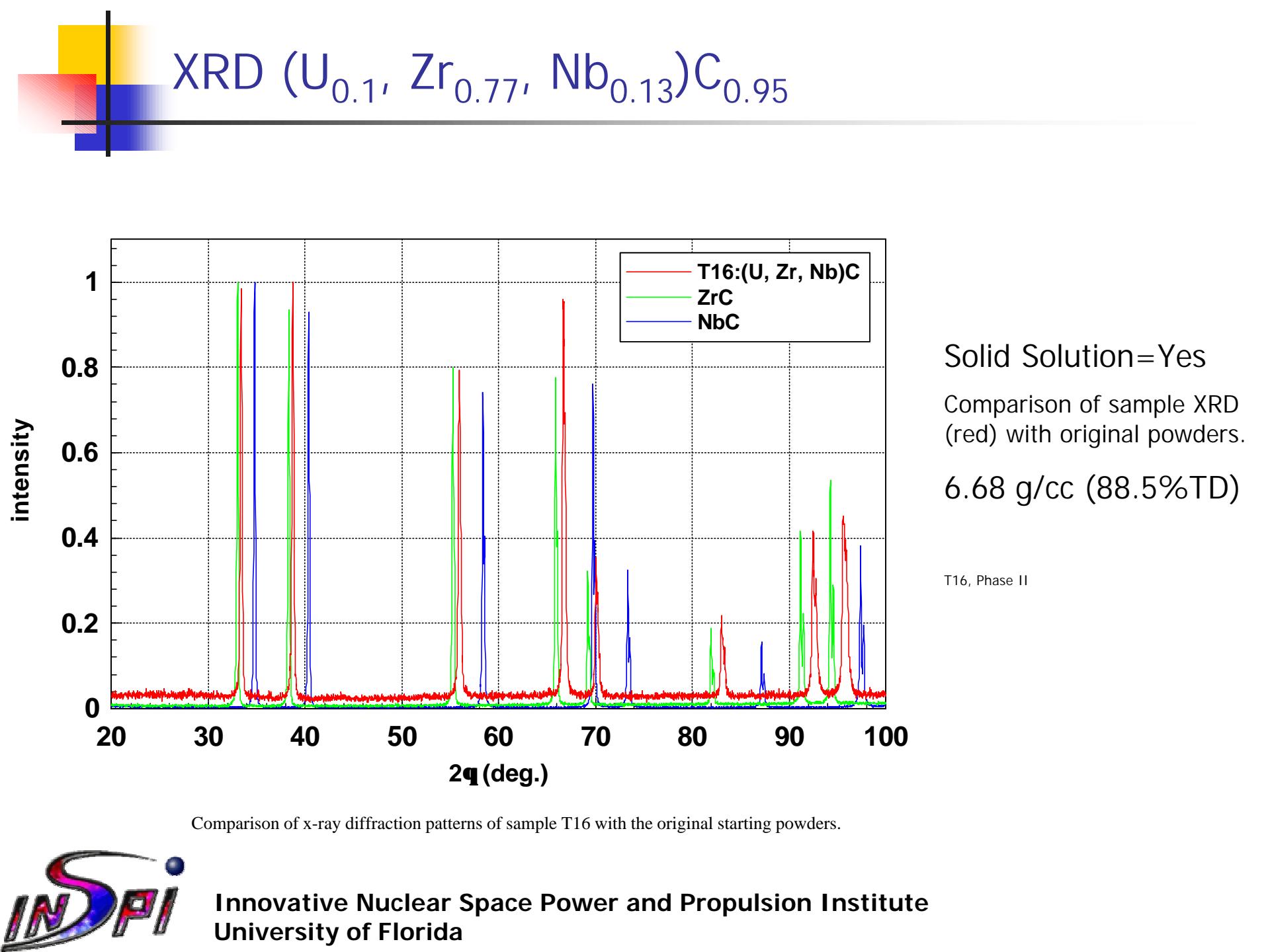
Solid Solution=Yes  
7.28 g/cc (96.5%TD)

T16, Phase II



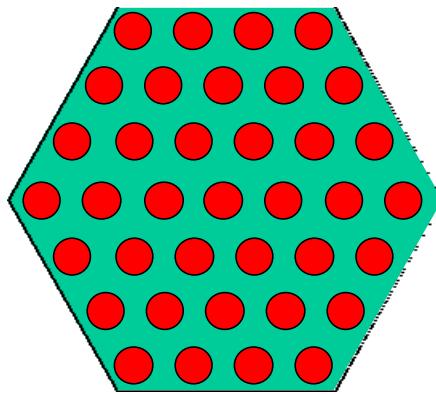
Innovative Nuclear Space Power and Propulsion Institute  
University of Florida

# XRD ( $\text{U}_{0.1}$ , $\text{Zr}_{0.77}$ , $\text{Nb}_{0.13}$ ) $\text{C}_{0.95}$

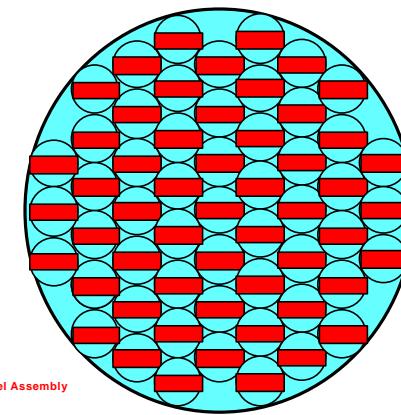


# Various Solid Core Fuel Forms

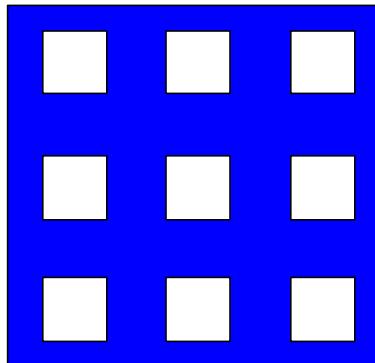
(a)



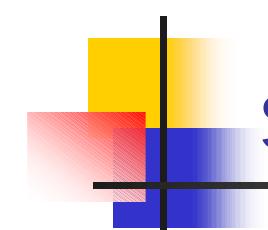
(b)



(c)



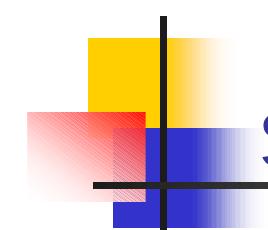
- a) Rover/NERVA
- b) Russian Twisted Ribbon
- c) Square Lattice Honeycomb



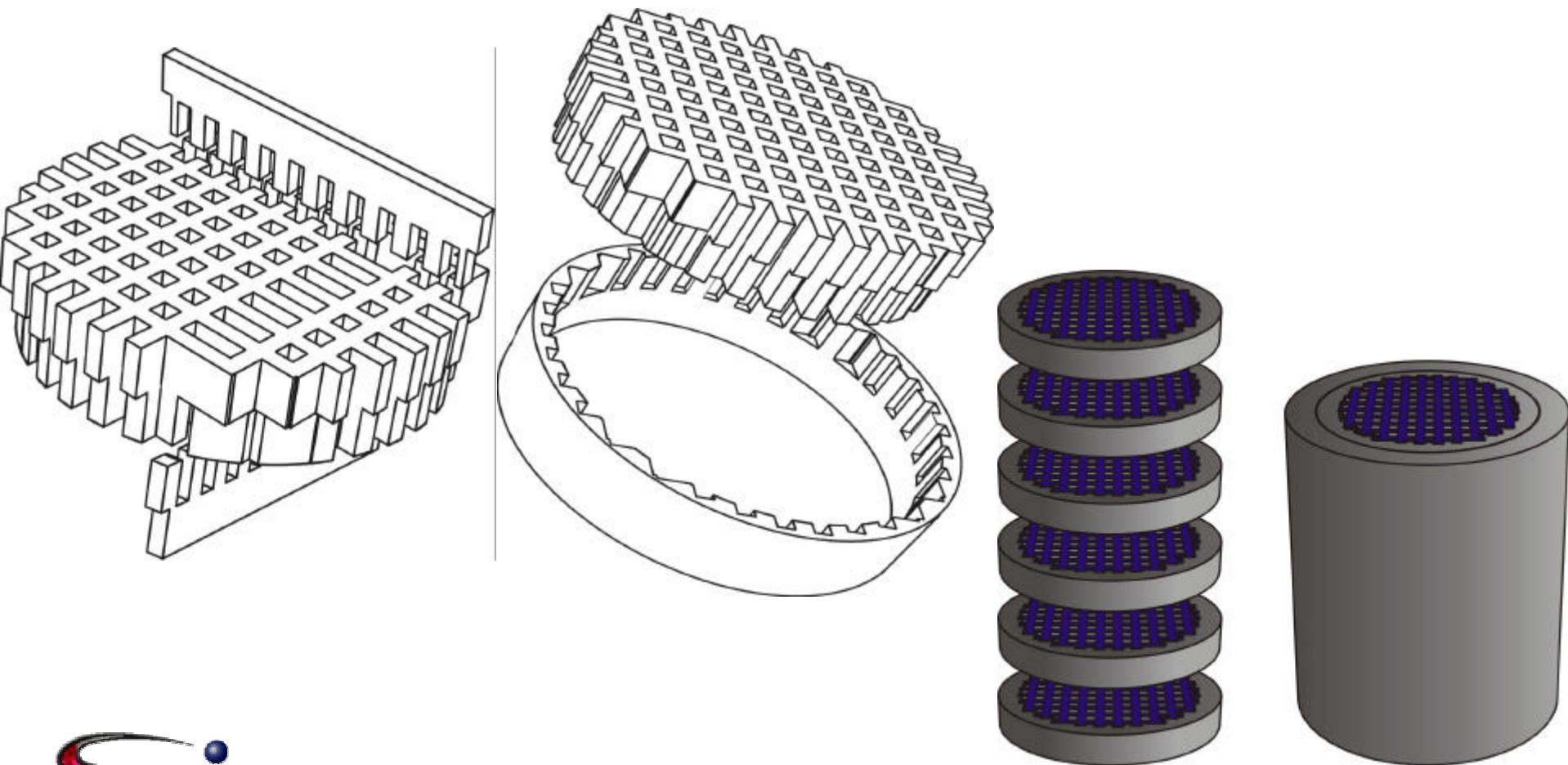
# SLHC Reactor for Electric Power and Propulsion

- SLHC Reactor is an ultra-compact, lightweight, and high temperature reactor
- SLHC Reactor is designed to power multi-megawatt NEP, NTP, or both systems.
- Power in SLHC Reactor is scalable from multi-kilowatt to multi-megawatt.
- In NTP mode, SLHC Reactor generates 5,000 to 50,000 lbf of thrust with Isp=1000 s.

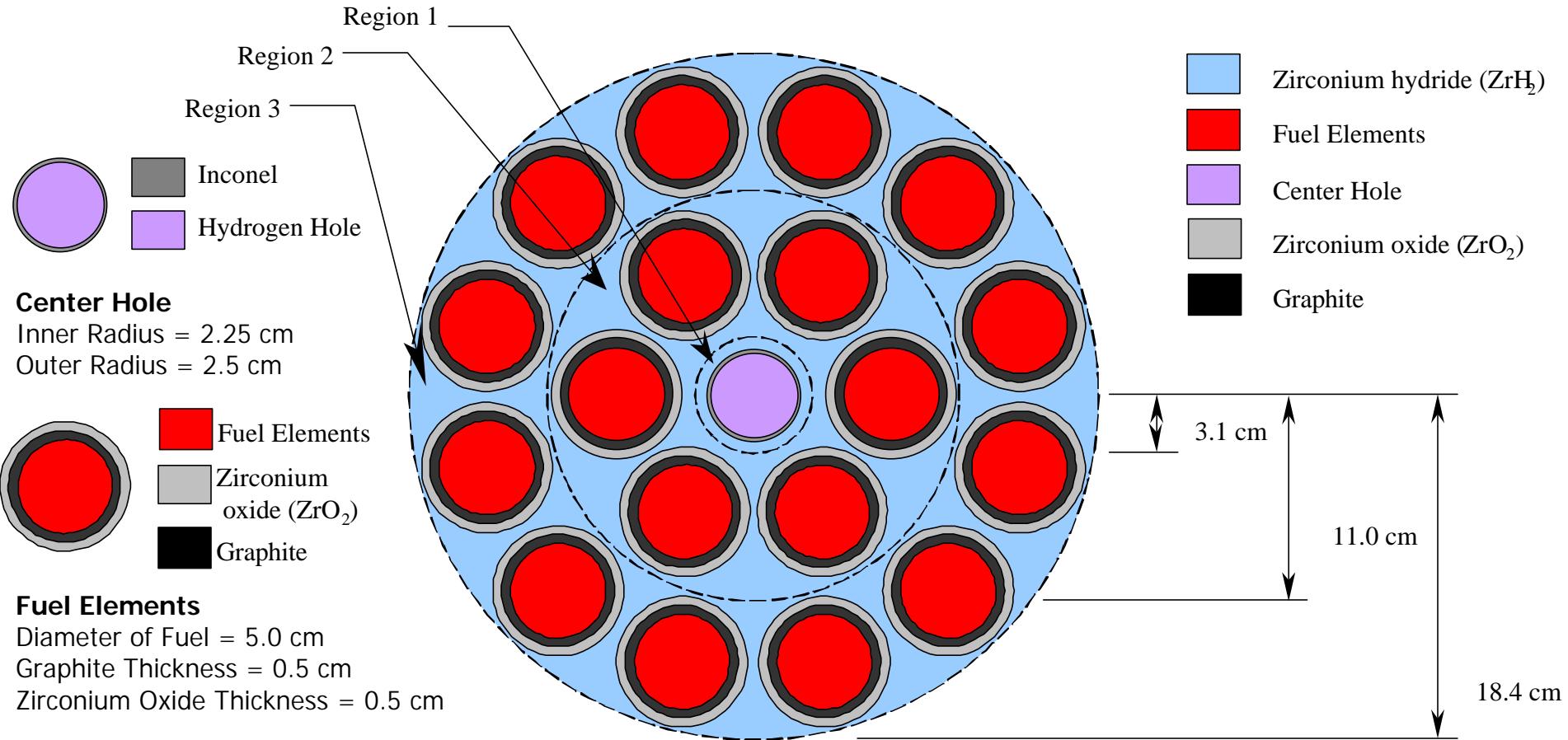


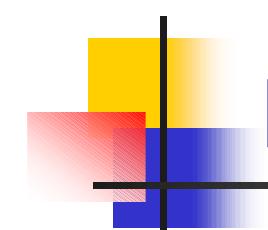


# Square Lattice Honeycomb Carbide Fuel Elements



# Reactor Description





# Reactor Description

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## Moderated Square-Lattice Honeycomb Reactor properties

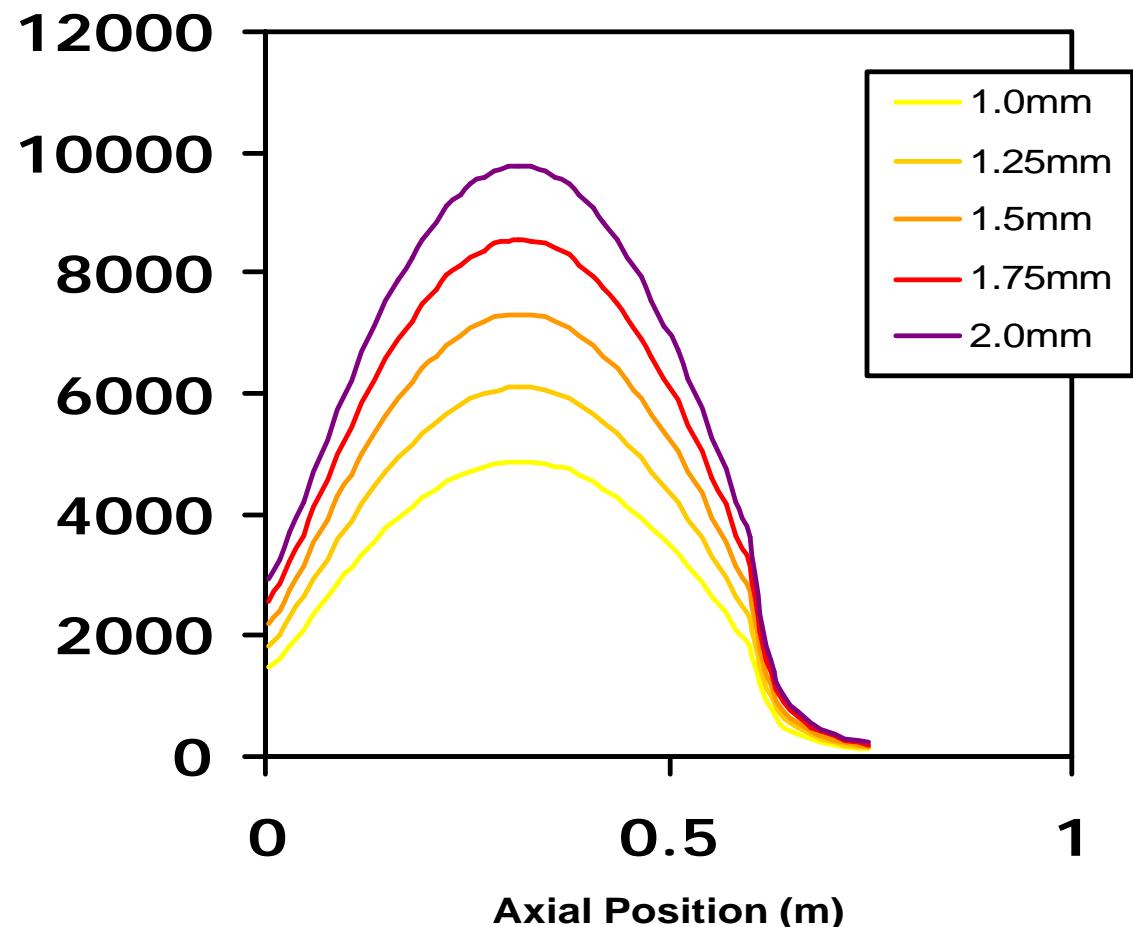
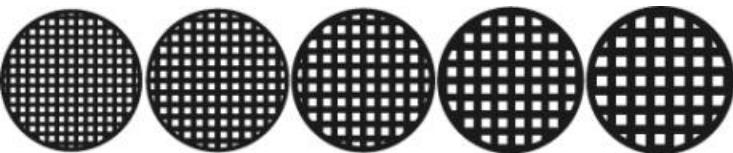
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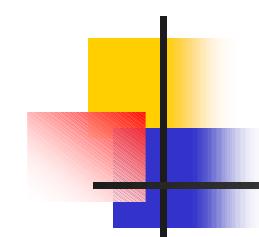
Properties	Value
Diameter (cm)	36.8
Height (cm)	50.0
Radial Reflector thickness (cm)	10.0
Top Axial Reflector thickness (cm)	10.0
Bottom Axial Reflector thickness (cm)	0.0
Thickness of Fuel Assembly (cm)	10.0
Fuel Type	Solid solution of (U,Zr,Nb)C
Fuel Enrichment (%)	93
Uranium Density (g/cm <sup>3</sup> )	0.4 - 1.0
<sup>235</sup> U amount (kg)	9.2
Propellant	H <sub>2</sub>

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# Heat Flux [kW/m<sup>2</sup>] for Constant Thrust

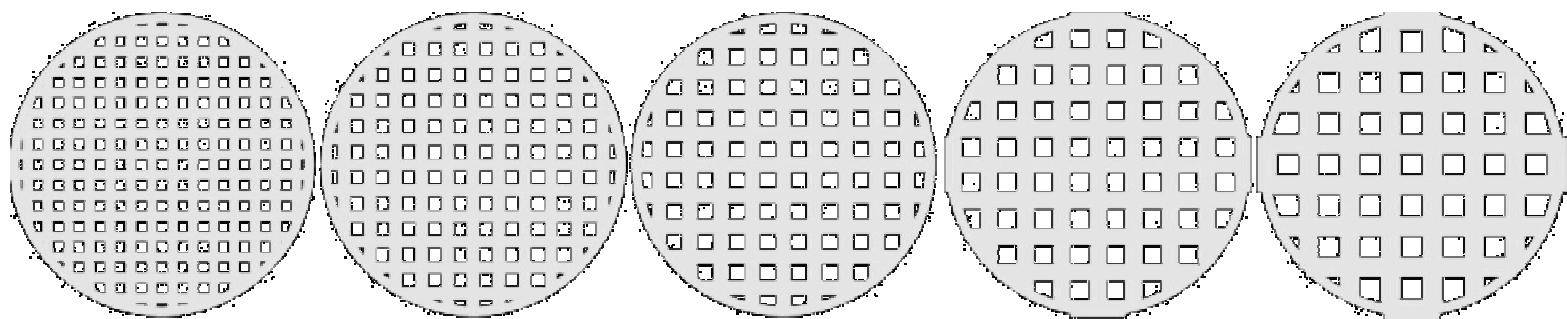
- Power remains constant for each thrust
- Total surface area decreases for increasing wafer thickness

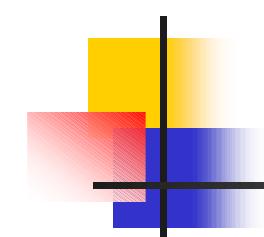




# Flow Area vs. Wafer Thickness

- Thicker = Stronger
- Must maintain 30% void in core to match criticality calculations
- Thicker = Fewer and larger coolant channels





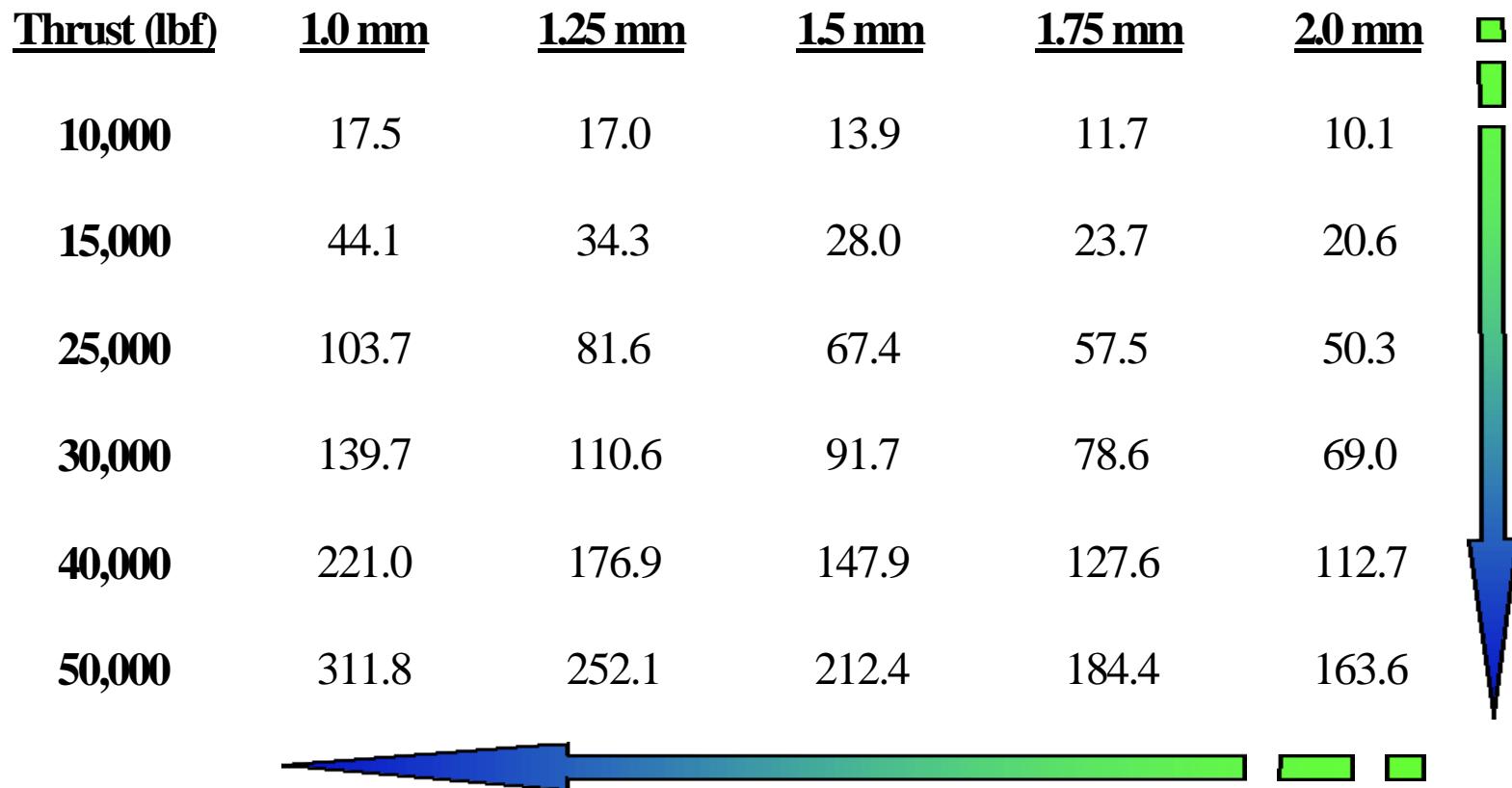
# Void Fraction

Pressure drop most significant effect

- Relative difference almost 19 times more than that for temperature change

Void Fraction	Max Surface Temperature (K)	Max Centerline Temperature (K)	Core Pressure Drop (psi)
20 %	2875	2910	265.3
30 %	2972	3024	91.73
40 %	3229	3228	39.17

# Total Core Pressure Drop

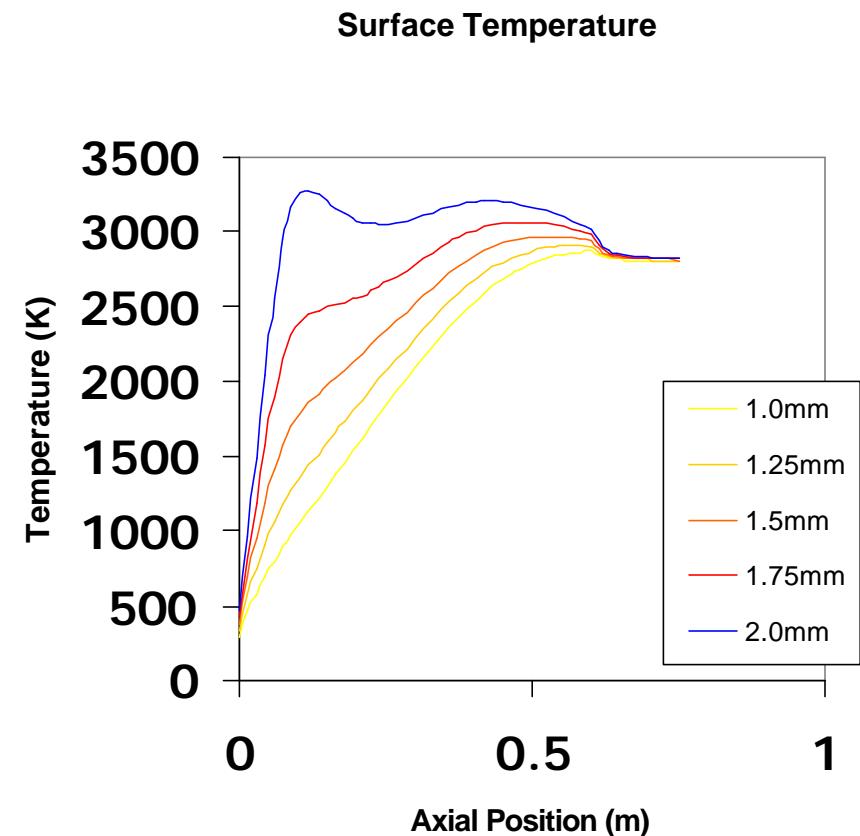
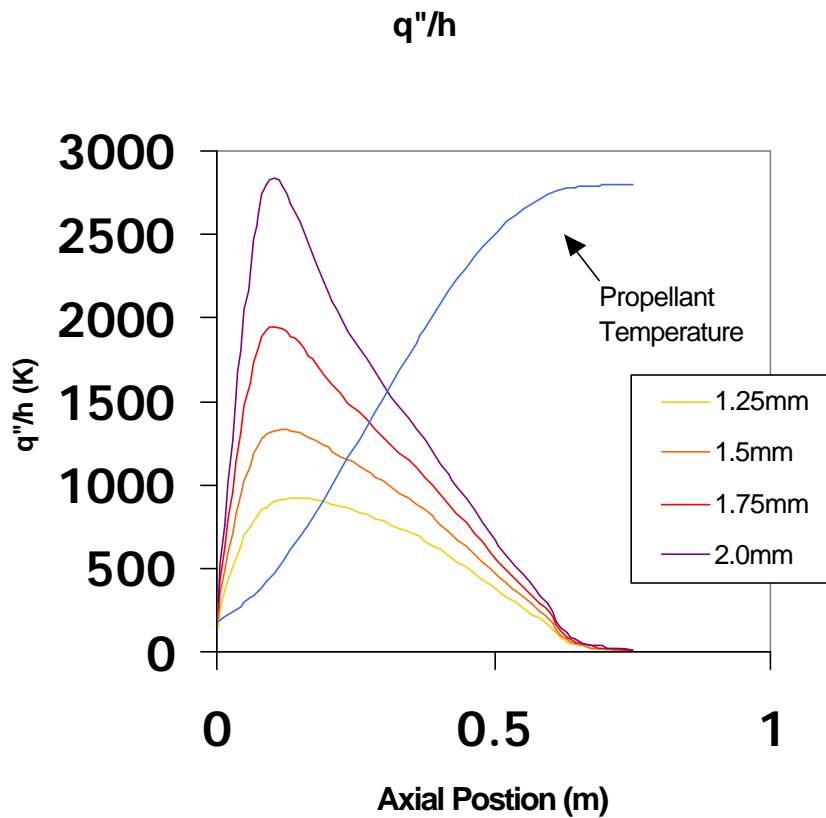


# Maximum Fuel Centerline Temperatures

<u>Thrust (lbf)</u>	<u>1.00 mm</u>	<u>1.25 mm</u>	<u>1.50 mm</u>	<u>1.75 mm</u>	<u>2.00 mm</u>
<b>10,000</b>	2840 K	2876 K	2923 K	3043 K	3131 K
<b>15,000</b>	2872 K	2917 K	2974 K	3048 K	3160 K
<b>25,000</b>	2876 K	2927 K	3004 K	3112 K	3272 K
<b>30,000</b>	2880 K	2938 K	3024 K	3152 K	3375 K
<b>40,000</b>	2892 K	2963 K	3068 K	3230 K	3970 K
<b>50,000</b>	2903 K	2989 K	3119 K	3311 K	4583 K



# Surface Temperature for Constant Thrust



# SLHC Weight Performance

Thrust Level (lbf.)	5000	10000	25000	50000	75000
Core	680	680	680	680	680
Support structure	36	53	115	250	425
Internal shield	181	201	250	300	310
Axial reflector	103	103	103	103	103
Radial reflector	599	599	599	599	599
Valves & Controller	320	348	425	525	590
Pressure vessel	314	376	550	800	1000
Upper core assembly	170	182	220	300	400
Nozzle skirt	50	100	250	500	750
Turbopump	35	45	75	125	175
Thrust structure	269	315	440	600	700
Total engine (lb.)	2758	3003	3708	4783	5733
<b>T/W</b>	<b>1.8</b>	<b>3.3</b>	<b>6.7</b>	<b>10.5</b>	<b>13.1</b>

# SLHC Weight Performance

